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Landsat Data for Current Land Cover and Use Classifications

Milk River Project

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LANDSAT DATA FOR CURRENT LAND COVER AND USE CLASSIFICATIONS:

MILK RIVER PROJECT

by

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Edmonton

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ABSTRACT

The integrated resource planning program in Alberta facilitates a comprehensive allocation of natural resources to varying degrees of protection and development. This has been made possible through the development of an interdisciplinary decision-making process since 1977, which relies on information from several disciplines. A specific aspect of social and environmental data bases is the subject of this report.

Current land use and land cover information has been recognized by interdisciplinary teams of resource specialists to have value during the planning process. Because traditional sources of this information have limitations, this study was undertaken by the Resource Evaluation and Planning Division of Alberta Energy and Natural Resources to identify a complementary source. This report explores the feasibility, limitations and advantages of using digital Landsat data in conjunction with simple interpretive aids as a source of current information for medium-scale mapping of regional (1:250 000 to 1:500 000) and sub-regional (1:100 000) land covers and uses.

The report concludes that the procedure developed over the course of the investigation is best for sub-regional land cover and use mapping and has greatest potential for application at the sub-regional planning level. Costs to produce a land cover and use classification map for an average planning area of 4 000 square kilometres have been estimated at $8 550 (1983 dollars). Because some of the costs incurred in the production of the classification are currently absorbed by the Alberta Remote Sensing Center, actual cost to Alberta Energy and Natural Resources would be $3 400 (1983 dollars). Acquisition costs of digitally-derived land cover and use maps versus conventional air photo-derived land cover and use maps were also estimated. It was concluded that the digitally-derived maps were cheaper to produce on a cost per unit area basis; $2.14 per square kilometre as compared with $2.61 per square kilometre for photographically-derived maps.

The greatest limitations in the use of digital data were the time and cost considerations. While a rigorous supervised classification of this data produced good results, the process was more time consuming and expensive than had been originally speculated. The report subsequently concludes that the usefulness of digital Landsat data as a complementary source of land cover and use information must be weighed against the overall costs incurred.

Finally, the report addresses potential future applications of digitally-derived land cover information in the integrated resource management planning program. It proposes the unsupervised classification could become a useful tool for the development of Ecological Land Classifications and that supervised classifications of land cover may be particularly practical when applied during the planning process in the resolution of specific resource management problems or issues.

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1. INTRODUCTION

Sub-regional integrated resource planning enables a comprehensive allocation of natural resources in Alberta to varying degrees of protection and development. The formulation of alternative resource allocation concepts in this interdisciplinary decision-making process relies upon information from social, political, legal, economic and environmental disciplines, but is ecologically-based. That is, the environmental data base is a central component as it serves to establish a baseline for decisions by identifying resource capabilities and sensitivity of the environment to resource use. An evaluation of this information with current land uses has enabled planning teams to identify potentials for resource development or use and secondly, has identified land uses which are environmentally detrimental. Land use and cover information has traditionally been provided in the form of legal land disposition maps and integrated biophysical maps produced in an inventory and evaluation process known as Ecological Land Survey (ELS). While these sources have proven very useful, certain inherent limitations have prevented an optimal use of this data.

Legal land use dispositions are not always good indications of land uses. A mapped timber development disposition, for example, will indicate a commitment of the forest land base to timber production, but fails to give a "picture" of harvesting magnitude. Deeded or patented lands do not indicate how these lands are used. This information is important in establishing use trends and projecting demands on adjacent Crown lands. Legal land use dispositions are also tedious and costly to map currently because storage and retrieval of this information has not been automated to the degree currently needed.

Land cover data obtained through the ELS have two significant limitations. First, the comprehensiveness of an ELS has a formidable time-related cost. The Ecological Land Classification (ELC) component of the ELS can depending on the size of the planning area take up to a year to complete. This factor can prevent the planning team -- composed of resource management specialists -- from developing a common appreciation for the "lie of the land" at the beginning of the planning process. Such an overview is beneficial to the team because it provides a conceptual context for the development of planning units. The planning units are used by the team members for the compilation of sectoral resource data and subsequently, for the development of resource management objectives. The planning unit boundaries are based on physical or ecological criteria wherever possible and not administrative criteria (e.g. forest management units, wildlife management units). This design feature has an important function in that it allows the team members to communicate in common spatial terms. Secondly, the ELC does not by virtue of its design (Lacate, 1969) identify land cover characteristics to a high order of specificity at the ecosection level (1:250 000 to 1:50 000). This level of landscape generalization does not, for example, identify biotic communities in early seral stages. Landscapes altered by anthropogenic or natural forces (e.g. fire) are also not identified. This information has its place in integrated resource planning. Ecosite (1:50 000 to 1:10 000) and ecoelement (1:10 000 to 1:2500) levels of landscape generalization would provide this information, but have not been used in integrated resource planning because of the large time and financial investments involved, and because such detailed large-scale landscape classifications are not required for general planning purposes. While the absence of this information is not very significant when it comes to the identification of planning units, it can be significant later in the planning process when resource allocation policies are established. The identification of an inexpensive land cover information source, which could augment the information obtained from an ecosection ELC, is consequently desirable.

This pilot project was undertaken by the Resource Evaluation and Planning Division of Alberta Energy and Natural Resources in conjunction with the the Alberta Remote Sensing Center to examine the feasibility, limitations and advantages of using digital Landsat data in conjunction with simple interpretive aids as a complementary source of current land use and cover information. Three objectives are derived from this project goal:

1. To determine whether the process developed for land cover and use mapping using digital Landsat data can be applied at regional (1:250 000 to 1:500 000) and sub-regional (1:100 000) scales of integrated resource planning.

2. To determine whether Landsat data are a practical source for land cover and use information from technical and financial perspectives.

3. To compare the digital Landsat data approach for land cover and use mapping to the conventional air photo interpretive method.

2. LITERATURE REVIEW

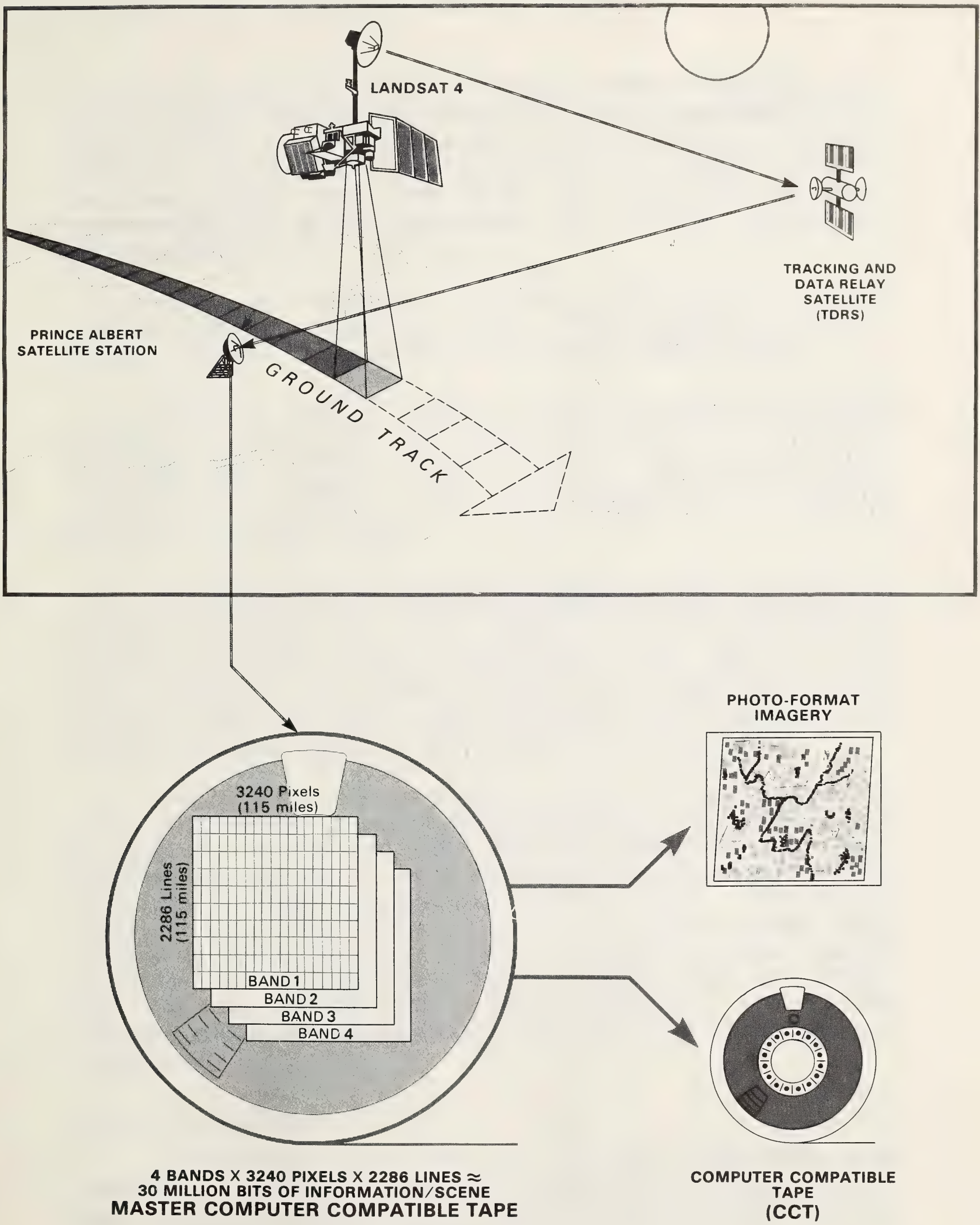
The Landsat satellites have been a valuable and prolific source of remotely-sensed Earth resource data since the first Landsat was launched in July, 1972. Use of these data grew gradually at first until processing and information extraction techniques became more advanced. The application of Landsat data to practical problems in resource monitoring and management expanded greatly in conjunction. Two more satellites were launched in 1975 and 1978, enabling applied research to continue.

Eleven nations today have the capability to directly receive and generate image products from Landsat. In addition, more than 100 countries now make use of Landsat data for resource evaluation and management. The practical applications of Landsat data have been found in minerals exploration, agriculture, land use monitoring and planning, forestry, range management, water management and map production (NASA, 1982).

There have been two generations of Landsat satellites since 1972. The first generation was represented by Landsat 1 through to 3 which were originally designed for research and development purposes. All data acquired from these satellites were received from the Multispectral Scanner Sub-system (MSS). This sensor system remained much the same in design for all three satellites. Today, only Landsat 4 and 5 are operational.

The second generation of Earth-sensing capability was brought into use after nearly a decade of developmental work. This new system is known as Landsat 4, and it was launched on July 16, 1982. Like previous Landsats, 4 scans the Earth in a repetitive, circular, sunsynchronous, near polar orbit, but at a slightly lower attitude of approximately 705 km (431 mi.). Each orbit takes nearly 99 minutes for a total of 14 1/2 orbits per day. Coverage of the Earth occurs over 16 days. MSS scene data is transmitted to ground stations around the world where it is processed into user-ready computer-compatible tape and photo-format imagery (Figure 1).

The impetus for the Landsat 4 program came from an appreciation of limitations in the performance of the MSS aboard earlier Landsats.


LANDSAT 4
TRACKING AND DATA RELAY SATELLITE (TDRS)
PRINCE ALBERT SATELLITE STATION
GROUND TRACK
3240 Pixels (115 miles)
2286 Lines (115 miles)
BAND 1
BAND 2
BAND 3
BAND 4
PHOTO-FORMAT IMAGERY
4 BANDS X 3240 PIXELS X 2286 LINES ≈ 30 MILLION BITS OF INFORMATION/SCENE
MASTER COMPUTER COMPATIBLE TAPE
COMPUTER COMPATIBLE TAPE (CCT)

Source: After Alberta Remote Sensing Center

Figure. 1 LANDSAT MSS DATA AQUISITION, STORAGE AND PRODUCTS

A new sensor system with improved spatial resolution, spectral separation, geometric fidelity and radiometric accuracy was needed and subsequently became the subject of a design effort initiated in the early 1970s. The second generation of Earth-sensor that emerged is called the Thematic Mapper (TM). The TM has more than twice the ground resolving power of its MSS predecessors; 30 X 30 metres compared with 80 X 80 metres[1].

Landsat 4 is operational, but it has experienced many technical problems which have affected its imaging and data transmission capabilities. Landsat 5, its successor, was launched in March, 1984.

Since the launch of Landsat 1 in 1972, it has generally been accepted that imagery would be a logical source of data for differentiating land uses and covers. It has only been within the last several years that mapping techniques and corresponding software and hardware systems have advanced to a level where reliable results could be attained at reasonable costs.

One of the earliest and most comprehensive studies of satellite data for land cover classification was conducted by the United States Department of Agriculture, Forest Service, in co-operation with the National Aeronautics and Space Administration (NASA) (Heller, 1975). After 24 months of study, Heller concluded that Landsat was an ideal source for first level multi-stage inventories. This finding confirmed the value of Landsat data for reconnaissance level application.

The current literature cites many examples of land cover inventories using computer processed Landsat data since this work began over 12 years ago. It is generally concluded that computer-assisted classifications are superior to and preferable to classifications of land cover from air-photo interpretation (Aldrich, 1979). The digital format provides the user greater flexibility, and digital images can be enlarged to any desired scale without the loss of inherent spectral resolution. An enlargement of a digital image for large scale assessment does result in the loss of spatial resolution; however, this technical problem is also experienced with the use of conventional air photography.

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[1] Landsats 1, 2 and 3 had pixel coverage of the Earth which equalled 80 X 80 metres. Because of overlap between pixels, original data was only received for a 56 metre X 79 metre component of each pixel. There is no pixel overlap for Landsats 4 and 5.

In relation to a conventional controlled air photo mosaic, a digital image has consistent spectral tonal qualities and has reasonable spatial accuracy provided medium scales are used, or excellent accuracy provided the image is corrected and used in conjunction with standard planimetric maps. The use of a digital image, corrected to the Universal Transverse Mercator grid, minimizes distortion and the tedious manual task of matching individual photographs for mosaic preparation. This correction must be completed before an accurate classification of land cover can begin.

Gregory (1978) cited other advantages of Landsat data over aerial photography which make it a valuable planning tool, these are: The synoptic scale -- allows interpreters to view land features as a whole (e.g. ecodistricts, rivers, geological features); Spectral sensing -- emphasizes reflectance contrasts between features which, when decoded, can assist in recognition and classification; Repetitive coverage -- can be used to monitor existing areas and to take advantage of seasonal enhancements and phenological study to aid in classifiction or to build a comprehensive picture of ecological and seasonal dynamics in target areas; and Global coverage -- available, subject to normal climatic restraints (cloud cover), anywhere in the world except for areas in the high Arctic and Antarctic (north of 80° N and south of 80° S).

Campbell and Sutherland (1982) identified many significant implications surrounding the use of digital image analysis. From a positive perspective, a digital image is useful because it contains the maximum amount of data acquired by the satellite. This data set can be processed into photographic images, but this only degrades or reduces the data presented because of the inability of normal film formats to reproduce every pixel. With digital analysis, the original data set can be optimized. Campbell and Sutherland suggest that many of the disadvantages attributed to digital analysis are in terms of expense and convenience and not results. Acquisition costs for image analysis systems are relatively high: an image analysis system is expensive to purchase if one is not readily available, and computer compatible tapes (CCTs) are the most expensive Landsat single scene products available. In addition, operation of a digital analysis system requires some familiarity with the basics of interactive computer processing. Unlike optical or "eyeball" image analysis, the use of digital data requires considerable prerequisite computer training and familiarization with the system to be used.

A resource inventory in the San Juan National Forest in Colorado produced a land cover map from Landsat MSS data in combination with high-altitude colour infrared photography and ground data that local resource management personnel considered to be as good or better than those produced by conventional photographic techniques at a much higher cost (Krebs and Hoffer, 1976). Wong (1979), Pala, Ellis and White (1981) and Hill-Rowley and Enslin (1979) conducted reconnaissance level land use and land cover classifications and concluded that Landsat - generated products were as good or better and less expensive than those produced conventionally. Van Ravenswaay-Claasen (1981) found Landsat provided a potentially cost-effective approach to reconnaissance level ecological and terrain data assessments. He concluded that recent images of study areas served well as a base for the integration of existing resource, ecological and cultural information, or as a primary source of new information.

3. PROJECT STUDY AREA

The study area, located in southern Alberta (Figure 2) adjacent to the United States border, covers an area of approximately 13 600 square kilometres (5 250 square miles). It contains several regionally significant physiographic and ecological features. The Milk River Ridge in southwestern Alberta and the Cypress Hills in the northeast rise approximately 450 to 760 metres (1 476 to 2 493 feet) above the adjacent plain. The study area is carved by numerous glacial spillways which were created as the Laurentide glacier retreated to the northeast (Beaty, 1976). The Milk River Canyon is the most significant representative. The Whiskey Gap, Lonely Valley, Middle, Kipp and Verdigris Coulees once carried Laurentide glacial melt waters to the headwaters of the Milk River within the study area. The Etizikom, Chin and Forty Mile Coulees drained via the Pakowki Lake Basin (Pakowki Lake) into the Milk River further downstream.

The character of the landscape has been strongly conditioned and controlled by the Laurentide glacier. Much of the landscape consists of a rolling hummocky till plain, which itself consists of a mantle of ablation moraine of variable thickness.

The study area is situated in the short- and mixed-grass ecoregions of Alberta (Strong and Leggat, 1981). Shrub communities consisting of buckbrush and wolf willow occur on moist sites. Cottonwoods, willows and waterbirch can occur along stream banks and floodplains.

Arable agriculture (cultivation) is the dominant land use in the study area. Approximately 60 per cent of the area is privately owned. Domestic livestock grazing is the most common land use on the remaining 40 per cent which is publicly owned.

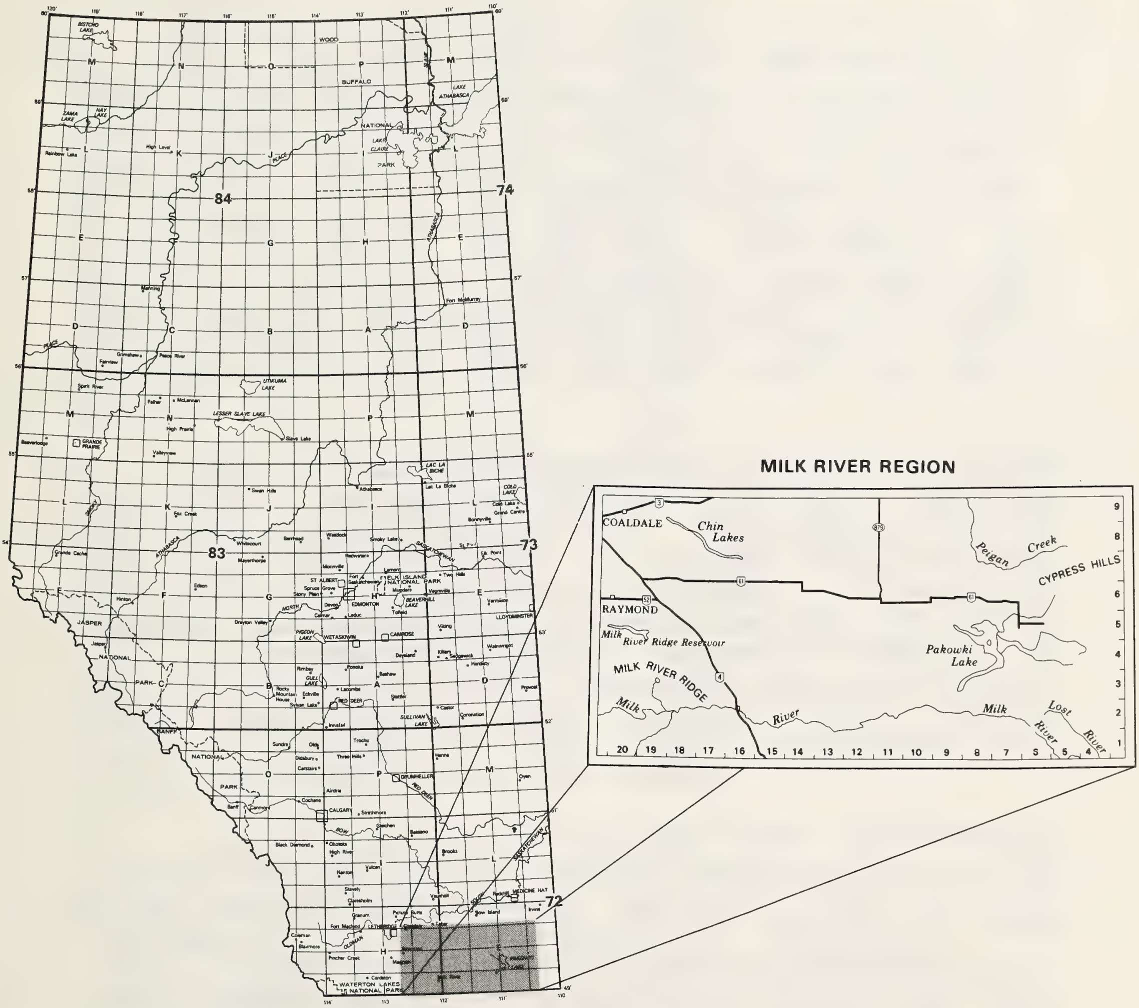


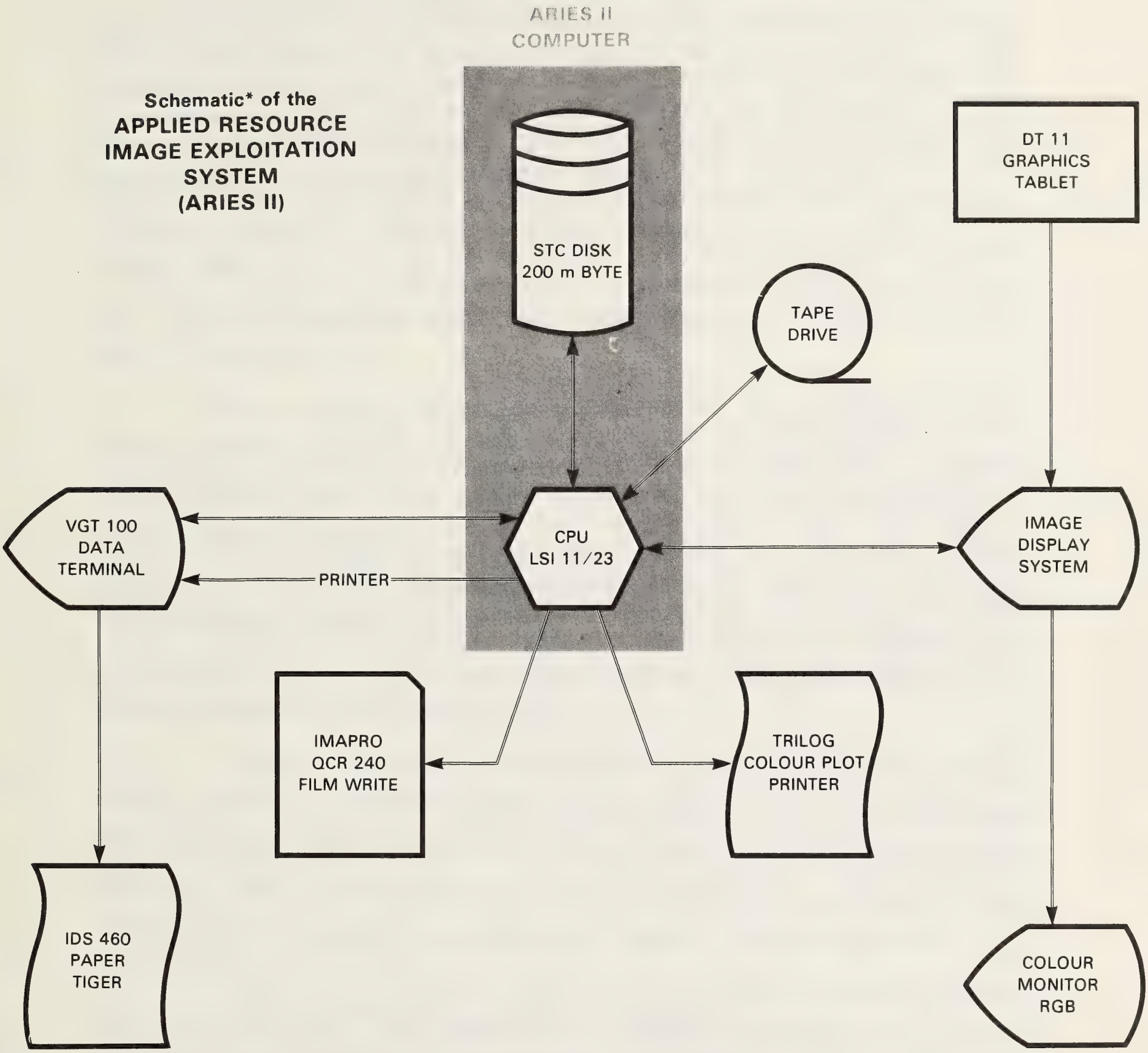
Figure. 2 MILK RIVER REGION STUDY AREA

4. METHODS AND RESULTS

The classification of Landsat data for land cover and use in the study area was achieved through interactive image processing on a digital computer analysis system operated by the Alberta Remote Sensing Center of Alberta Environment. The Applied Resource Image Exploitation System (ARIES)-II LCT-11 image analysis system used over the course of this study was based on a DEC LSI 11/23 microcomputer and included: 14" 200 megabyte disk and drive, nine track 800/1600 BPI tape drive, operator's CRT terminal, IDS 460 matrix printer/plotter, high-resolution 19" colour monitor with six megabits of video memory (VRAM), graphics tablet for video manipulation, TRILOG matrix colour printer/plotter and IMAPRO QCR-240 colour image recorder (Figure 3). Significant modifications to the system have been made at the time of printing.

Before the classification could begin, a suitable image(s) had to be selected. This selection is critical if the desired results are to be achieved (Bonner, Rohde and Miller, 1981; Strahler, Logan and Byrant, 1978; and Kalensky, 1974). The scene must display parameters which will be used to conduct the classification. For example, if vegetation vigor is an important parameter the best scene date would be found during the peak growing period of the species in question. An August 25, 1981 Landsat 2 scene was subsequently chosen on the basis of standard selection criteria - minimal atmospheric distortion and cloud cover, contrast between land covers, and its representation of a typical range of seasonal land covers and uses.

A geometric correction of the Landsat scene was performed in conjunction with the Universal Transverse Mercator grid and 1:50 000 National Topographic Series map data. More than 80 control points were established for the geometric correction and resulted in a linear accuracy of better than 1.0 pixel following the transformation. This exercise proved to be very time consuming and might have been avoided if Digital Image Correction System (DICS) scenes had been used. There were several limitations associated with DICS scenes, however, which precluded their use in this study. The costs associated with the acquisition of these precorrected images was too high. Several DICS scenes were required for study area coverage and this constituted a relatively high price and lengthy order turn around time. In addition, there was no guarantee that the scenes would be "spectrally compatible" if an existing inventory of DICS scenes had been used.



Schematic* of the **APPLIED RESOURCE IMAGE EXPLOITATION SYSTEM (ARIES II)**

* *Source: After Alberta Remote Sensing Center*

Figure. 3 APPLIED RESOURCE IMAGE EXPLOITATION SYSTEM (ARIES II) OPERATED BY THE ALBERTA REMOTE SENSING CENTER

A supervised classification was chosen for the project to attain the highest degree of confidence in the results. An unsupervised classification was also performed to serve as a control. The latter does not introduce subjective bias into the classification process since spectral classes are not defined on the basis of the operator's personal knowledge of the area, access to available resource base data, or simply a good educated guess. An unsupervised classification algorithm facilitates an assignment of spectral values to a predetermined number of classes on a statistical basis. In effect, the product generated from an unsupervised classification depicts classes of similar spectral units only. Land cover interpretation occurs after the product is generated and is not incorporated as an integral component of the algorithm.

One of the most significant limitations of the ARIES II image analysis system relative to this investigation became apparent during the employment of the Interactive Training (IT) algorithm for supervised classification. The entire study area could not be displayed in an undecimated format because of the limited size of the video memory. The option to decimate the original data set did not exist since it was crucial that the best ground resolution possible was used during the classification process. Sub-areas with the study area consequently had to be identified for classification. Each sub-area geographically represented approximately seven per cent of the study area or 880 square kilometres (340 square miles).

A second limitation was encountered during the ground verification process. Hard-copy preliminary classifications of sub-areas were required to assess accuracy against ground data. An undecimated classification was desirable for TRILOG colour plot printouts because the high physiographic and ecological diversity in the study area necessitated the use of the best ground resolution available. Scales of 1:50 000 and larger were chosen for sub-area TRILOG printouts.

A working scale of 1:50 000 was subsequently chosen in light of these limitations. The generation of TRILOG printouts at this scale also had the advantage that National Topographic Series (NTS) maps could be readily interfaced with preliminary classifications during the ground verification process. This feature significantly aided interpretation.

The establishment of these methodological parameters -- use of sub-regions for classification and a 1:50 000 working scale for ground verification -- had major implications on the scale of application.

The geographical limits of the classification were narrowed to relatively small areas for practical reasons. A regional scale land cover and use classification was no longer viable. Classification of these regions on the basis of relatively small sub-regions at a working scale of 1:50 000 would prove far too expensive and time consuming. The sub-regional supervised classification process generated a high degree of confidence in the results, but these results were associated with considerable expenditures of time (e.g. up to 40 hours of staff time, and 25 hours of computer time).

For each sub-region, training sites were established and applied using principles developed by Wong (1979) and Brooner and Simonette (1971). This essentially involved an interpretative process comprising of four stages: identification of a set of parameters or features common to a given class, selection of a site within the study area where these features were expected to occur, verification of features found at the site with those anticipated and extrapolation of this set of site features to other likely sites in the study area.

During the IT process, several sites were chosen for each land cover class on the basis of personal knowledge of the area, ground data, published and unpublished biophysical inventories and air photo interpretation. This extensive survey was a critical prerequisite to training site selection because surface covers common to a given land cover class had to be included in the training process. Failure to achieve this resulted in an incomplete classification of a given theme or unclassified pixels. This problem could be overcome with the establishment of additional training sites and/or slightly lower confidence limits during the signature generation (i.e. purity filtration) stage. These measures were repeated until the percentage of unclassified pixels was reduced to a reasonable range.

The land cover classes employed generally fell within the Canada Land Inventory Classification system for land use, but were modified to meet conditions common to the study area. Standard names for various classes were derived from a catalogue developed by Ryerson and Gierman (1979) and Anderson, Hardy and Roach (1972) when possible.

Small urban centres and linear features such as road alignments and utility rights-of-way were discernable, but the 50 X 50 metre pixel size[2] was a considerable limitation on resolution. No attempt was made consequently to classify these features by way of the supervised classification. Such features can be classified manually using a digitizing table. The Alberta Remote Sensing Centre does not have this hardware at present.

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[2] Landsat 2 pixel data conforms to 80 X 80 metres. These pixels are resampled by ARIES II statistically for an enhancement of ground resolution during the image-to-NTS map registration task.

Cultivated lands were readily identified because of their characteristic patterns. No attempt was made to classify crop types using the supervised classification algorithm. An agricultural land class was used to identify crop land but this was done manually during the generation of map products.

Major waterbodies and courses, riparian and wetland areas, grasslands, biologically-unproductive areas (exposed mineral soils and saline seep sites) were identifiable and were classified.

Ten was the largest number of land cover classes necessary at the 1:50 000 working scale. This maximum imposed a practical level of generalization, even for the most biologically and physically diverse sub-region. More detail not only resulted in a confusing classification, but also produced a high order of specificity, the accuracy for which could not easily be verified with existing resource inventory data and limited field time.

The diversity of land cover in the region suggested that land cover classes would vary from one sub-region to another. Therefore, the total number of themes for the study area would appear to be a function of sub-regional variability.

The Maximum Likelihood (ML) classification algorithm was used to classify watercourses, waterbodies, riparian and wetland areas, grasslands and biologically unproductive areas. This vigorous algorithm is based on a statistical decision criterion (maximum likelihood rule) to assist in the classification of overlapping signatures. Pixels are assigned in all available wavebands to the class of highest probability. The comprehensiveness of this pixel assignment proved to have a relatively lengthy computer processing time.

Some confusion or classification overlap between land cover classes became apparent over the course of this study because of the high degree of similarity of several spectral signatures. After repeated attempts at separation which included a variety of data manipulation techniques such as maximum likelihood and parallepiped processing, it was found that certain land cover classes could not be easily separated. Some signatures may have been more separable earlier or later in the growing season, however use of different scene dates (multi-temporal classification) was not a viable alternative because of the expense involved in acquiring additional computer compatible tapes (CCTs) and substantial increases in computer time required to process and interface these data. In short, the cost and time did not justify the results that might be achieved.

The accuracy of the final land cover and use classification for a preselected sub-region was determined on a class-by-class basis that involved field work and air photo interpretation. Although the dates of the Landsat imagery (August 25, 1981), air photo coverage (June, 1980) and the field investigation (May, 1983) did not coincide, changes in land cover were not considered to be very significant because of the rather slow rate of plant establishment and growth in this semi-arid region. In addition, no large recently altered or disturbed areas were expected. Satterwhite, Rice and Shipman (1984) drew a similar conclusion prior to field verification of land cover classes in a semi-arid region in the United States.

Field work entailed the selection of several sites from the classification map, followed by ground interpretation of physiographical and ecological features on-site. This deductive approach enabled considerable flexibility in the evaluation of the classification. For example, land covers assigned to the agricultural land class could be verified by the presence of cultivated land in the field; waterbodies and wetlands present in the classification but absent in the field could be verified by the geomorphology of and vegetation at the site.

Because the field investigation focused on the establishment of a general perception of classification accuracy, air photo interpretation was also conducted. A total of 64 test sites were selected (i.e. eight per class). The analysis revealed that six of the 64 sites had been misclassified, resulting in an 80 per cent accuracy rate. This finding was consistent with conclusions drawn following the field investigation.

Misclassification was highest in the water, riparian and rangeland high biomass classes. High biomass rangeland sites were often misclassified as water[3]. Shadows cast on north-west facing slopes of coulees were also misclassified as water. Some high biomass rangeland sites were found to be misclassified as riparian.

---

[3] It could not, however, be determined conclusively whether the misclassified waterbodies were, in all cases, really misclassified. The dryness of these sites in the field was not conclusive proof that misclassification had occurred because of their low-lying position and because evidence of hydric flora suggested inundation by water for short periods had occurred. Climatological information on precipitation for this period also indicated that rainfall had been usually high.

A scattergram of spectral values of rangeland high biomass and water land cover classes in bands five and seven[4] (Figure 4) confirmed that the separation of misclassified classes would be difficult, if not impossible, with this August, 1981 data.

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[4] Landsat 2 MSS data was used in this study and is formated in bands four, five, six and seven. Bands four and five, and six and seven are alike so it is common practice to use bands five and seven for two dimentional comparisons. (Landsats 4 and 5 format MSS data according to bands one, two, three and four.)

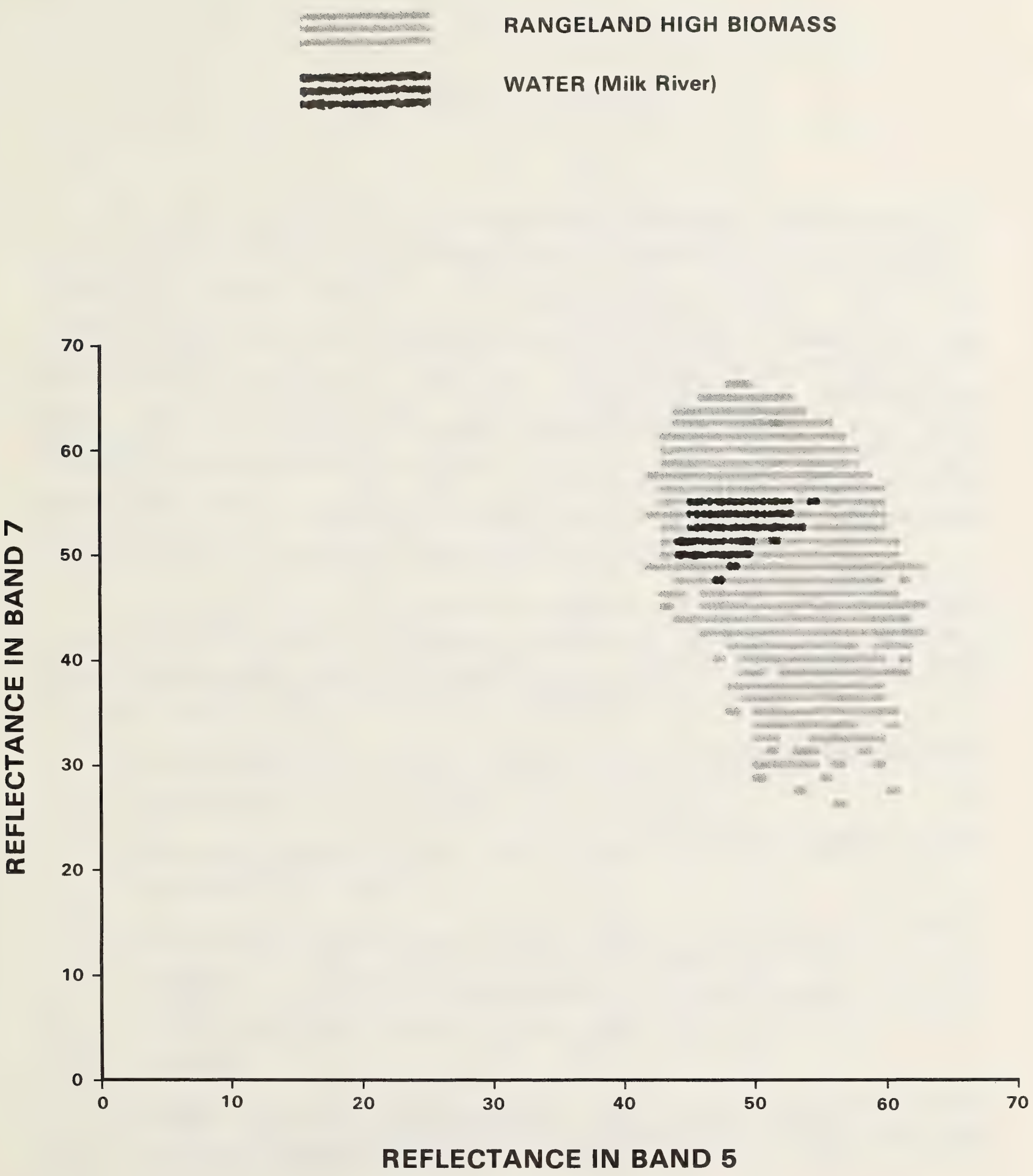

Figure. 4 SCATTERGRAM OF REFLECTANCE VALUES OF BAND 7 VERSUS BAND 5 FOR RANGELAND HIGH BIOMASS AND WATER LAND COVER CLASSES

5. ESTIMATION OF COSTS

In the pursuit of cost comparisons between a conventionally-derived land cover use classification which employs air photo interpretation as a primary source of information, and a Landsat data-derived classification, it is important to acknowledge two facts. First, the ARIES II image analysis system operated by the Alberta Remote Sensing Center was not designed for any given line production operational program. Its configuration was largely centered on general research and development and teaching. Second, time estimates reflect high user training and familiarization costs which also would not be part of an operational program. With these points in mind, the following is a discussion of cost differences between aerial photography and Landsat data-derived land cover and use classifications.

A comparative evaluation of financial and time costs to produce classifications based on different information sources (i.e. Landsat, aerial photography) required adherence to several conditions so that the map products could, in fact, be compared:

a) The location and size of the area to be classified and scale of map products to be produced must be the same.

b) The data source for the classification must have similar dates and should be recent.

c) The classifications must be uni-temporal as opposed to multi-temporal. The use of more than one date can lead to a more rigorous supervised classification. The costs associated with the acquisition and use of this data was a restrictive factor, however.

d) When logistical considerations (e.g. travel costs for field checks) between the classifications are similar they cancel one another.

e) The classifications should be as accurate as technically and financially possible.

f) Existing resource inventory information (vegetation maps, surficial geology, geomorphology, etc.) is equally available for both classifications.

g) State of the art techniques should be used whenever possible to produce the classifications.

h) Actual financial costs must be employed wherever possible (i.e. all costs, including those absorbed by government agencies due to special service policies, must be itemized).

With these major conditions in mind, a sub-region was selected for a comparative evaluation of incurred costs (Figure 5). This sub-region is located in the southeast corner of the study area and covers an area of approximately 880 square kilometers (340 square miles). It is one of the most physiographically and ecologically diverse areas in the Milk River region study area.

A breakdown of estimated financial and time costs to produce a photographic and digital Landsat classification at a scale of 1:50 000 is depicted in Table 1.

For cost estimates, two categories of parameters are outlined in Table 1. The data acquisition component reflects fixed costs for both photographic and digital Landsat methods. The photographic component would comprise three sources of raw data: 1) 1:50 000 stereo pair aerial photographs in colour and colour infrared[5], which would be used during the interpretive process for the delination of land cover and use classes; 2) a 1:50 000 controlled colour infrared mosaic, also to be used for interpretive purposes; and 3) a 1:50 000 colour mosaic onto which land cover and use classes would be transferred from the stereo pairs. It is important to recognize that the cost estimates for these products are based on federal and provincial government cost schedules, and not those of a competitive market.

The digital Landsat data component also contains three major elements. The first, known as a 1:1 000 000 MSS colour transparency was selected following a microfiche search for the appropriate scene date. This product is useful in the confirmation of image clarity; atmospheric distortion and cloud cover are not always very apparent in the black and white microfiche received from the ground station in Prince Albert, Saskatchewan. The 1:250 000 MSS colour print provided an excellent and inexpensive overview of the area to be classified.

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[5] Obtained from the Canadian Center for Remote Sensing.

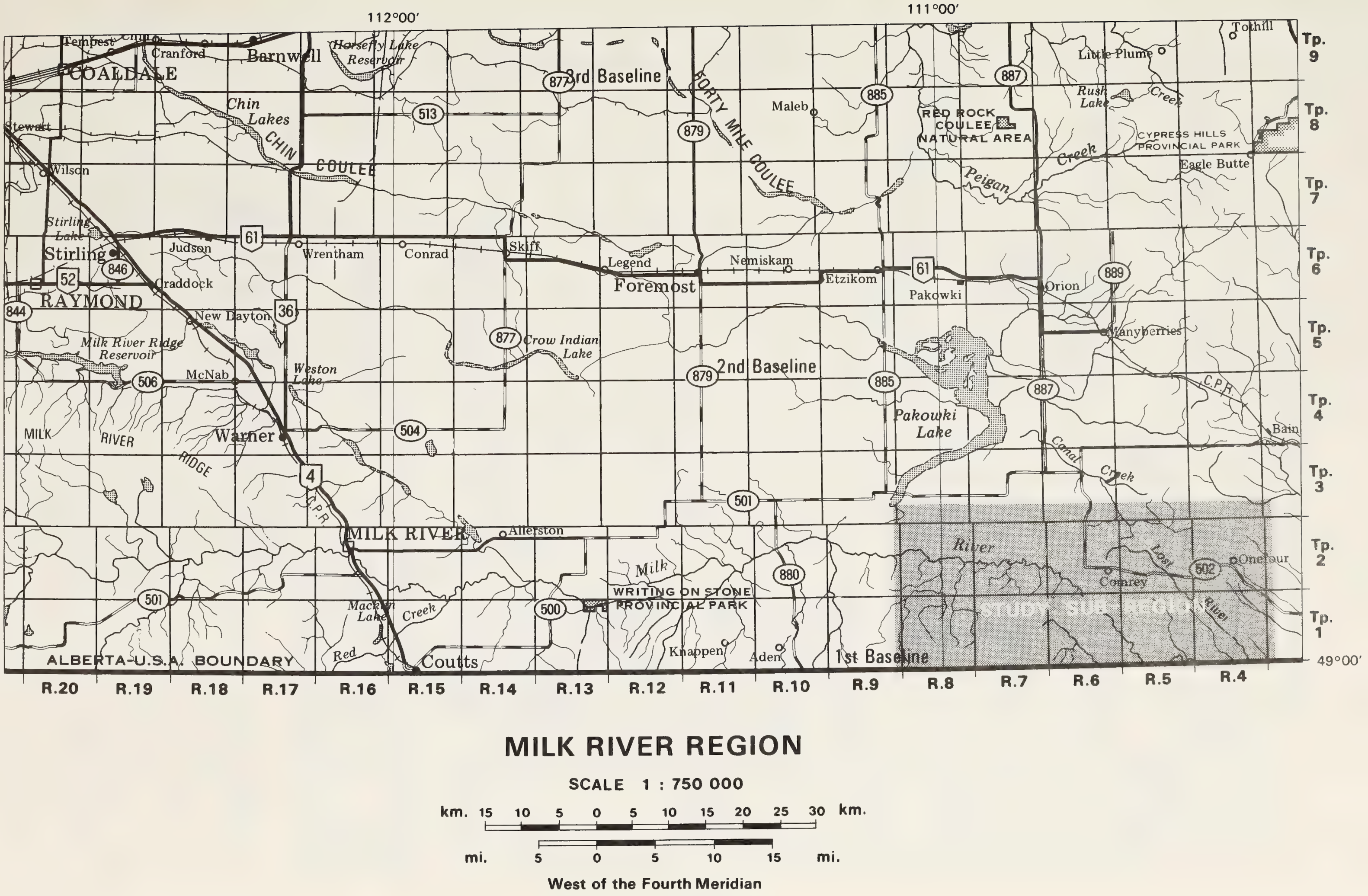

Figure. 5 LOCATION OF THE STUDY SUBREGION WITHIN THE MILK RIVER REGION

Table 1 COMPARITIVE ESTIMATES OF MONETARY COSTS[+] FOR PHOTOGRAPHIC AND LANDSAT DATA CLASSIFICATIONS

DATA PARAMETERS	PHOTOGRAPHIC		DIGITAL LANDSAT	
		Estimated Cost '83 $		Estimated Cost '83 $
DATA ACQUISITION	1. 1:50 000 Air Photo Coverage in colour	1 040.00	1. 1:1 000 000 Colour MSS Film Positive	23.40
	2. 1:50 000 Controlled air photo mosaic in colour.	126.00	2. 1:250 000 Colour MSS Print	95.40
	3. 1:50 000 Controlled air photo mosaic in colour infrared.	126.00	3. Landsat CCT-MSS 4 Band (30 000 km^2) coverage	243.80
NET COST		1 292.00		362.50
CLASSIFICATION	a) Manual Classification		A. Supervised* Classification	
	i) Manpower 63 hrs. @ $16/hr.	1 008.00	1. Manpower	576.00
			i) Resource Appraisal 24 hrs. @ $16 hr. ($384.00)	
			ii) Image Analysis System Technician** 16 hrs. @ $12 hr. ($192.00)	
			2. Computer Time** $250/8-hour day	943.75
	Net Cost	1 008.00	Net Cost	1 519.75
			B. Unsupervised* Classification	
			1. Manpower	
			i) Image Analysis System Technician 4 hrs. @ $12/hr.	48.00
			ii) Computer Time** $250/8-hour day	240.63
TOTAL COST	Data Acquisition and Manual Classification	2 300.00	Data Acquisition and Sup. Classification	1 882.25
			Data Acquisition and Unsup. Classification	532.43
COST PER KM^2	Data Acquisition and Manual Classification	2.61	Data Acquisition and Sup. Classification	2.14
			Data Acquisition and Unsup. Classification	0.61

+ Based on M12 Sub-region (880 square kilometers).

* Conducted at the Alberta Remote Sensing Centre.

** Estimates include approximate cost of geometric correction and high quality (applicon plot) map generation.

It is a very useful tool for geographically referencing features during the UTM correction of the image and for subsequent classification. Overlays of training site information provided a useful record for example. The third and most expensive product is the MSS 4 Band CCT, which contains raw digital data to be used during image processing.

In relative terms, the photographic data acquisition cost for this particular sub-region is 3.5 times greater than that for digital Landsat data: $1 292 compared with $362.

Classification, the second parameter in Table 1, identifies variable costs[6] associated with the actual designation of land covers and uses. Using data available from these cost estimates, it can be determined that the manual photographic classification is considerably more labour intensive than the supervised digital Landsat classification. This is largely due to the time consuming and mechanical process of designating and refining classes on air photographs and mosaics by hand once the criteria for each class has been determined. In a digital classification, once training areas are established with an appropriate statistical confidence, this task is performed automatically by the computer in a relatively-short time period.

Significant computer time and technical assistance costs are incurred when digital data are processed. Since the Alberta Remote Sensing Center currently does not charge public or private sector users of the ARIES II image analysis system, an actual cost structure was not in place. The $250 (1983 $) per eight-hour-day estimate was derived from the Ontario Remote Sensing Centre's operating cost for a similar system. The incorporation of this actual cost in the calculation of a total net cost of a supervised classification results in an expenditure of $1519.75, 51 per cent more than the total net cost of a photographically-derived classification.

In a comparison of total cost per square kilometre, the photographic classification is 22 per cent higher than the digital Landsat classification. This dramatic difference is largely the result of the high acquisition cost associated with the photographic products.

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[6] This cost is variable because the complexity of scenes to be classified is directly proportional to the time required to complete accurate photographic and digital Landsat classifications. It is important to note that an average variable cost estimate, taking into account several scene types, would more appropriately reflect incurred cost. Such an estimate, however, is beyond the scope of this project.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Present Applicability in Integrated Resource Planning

Over the course of this study it was concluded that digital Landsat data can best be applied in conjunction with sub-regional integrated resource planning. This planning level relies on a mapping scale of 1:100 000. Planning areas vary in size from approximately 900 square kilometres to 10 000 square kilometres, but average around 4 000 square kilometres. The factors lend themselves well to the procedure developed in this study for the supervised classification of land covers and uses. Use of the 1:50 000 working scale results in sub-regions of approximately 900 square kilometres in size. Assuming that the complexity of land covers and uses between planning areas is constant and not more complex than the study sub-region, a real cost of approximately $8 550 (1983) can be established for an average size sub-regional planning area. However, because the Alberta Remote Sensing Center currently does not charge for the use of computer time and technical assistance, only data acquisition and Alberta Energy and Natural Resources staff time costs would be incurred. This suggests that an average planning area can be classified at a cost of $3 400 (1983).

The 1:50 000 working scale classification can be generalized up to a scale of 1:100 000 digitally or photographically for general planning purposes at a relatively-small cost. A two-time digital reduction of the working scale to 1:100 000 will produce a land cover and use classification map that can be readily interfaced with other resource data for evaluative purposes.

The use of the classification procedure developed over the course of this study at regional scales of 1:250 000 and 1:500 000 would not be reasonable from a cost perspective even if computer time and technical staff costs are not incurred. Planning areas at these scales can range from 9 500 square kilometres (1:250 000) to well over 200 000 square kilometres (1:500 000).

6.2 Benefits and Limitations of Digital Landsat Data

The findings of this study tend to confirm conclusions of many users of digital Landsat data for medium, map-scale classifications of land cover and use. These data can be used at a cost comparable to that of conventional photographic data (see Table 1). While a comparison of accuracy between the two types of classifications was not conducted to identify margins of error, ground and air photo interpretation verification of 1:50 000 sub-regional Landsat classifications has established a high degree of confidence in the results. The degree of error inherent in the classification varies among classes of land cover and is related to the degree of variability in the data. A highly complex landscape, for example, will be associated with a higher degree of classification error than of one of lesser complexity.

Table 2 is a summary of the major benefits and limitations of the digital analysis of Landsat data relative to the conventional approach. Two considerations should be taken into account during the review of the benefits and limitations. First, the working scale chosen for the digital classification was limited by the spatial resolution of MSS Landsat data. Greater classification specificity might be achieved with the employment of TM Landsat data which has nearly twice the ground resolution. A working scale of 1:50 000 was found to be suitable for MSS data. This suggests that a scale of 1:25 000 could be possible with TM data and is stressed here to indicate that a satellite digital data in the future will have greater application potential. Secondly, the capabilities of the ARIES II LCT-11 image analysis system can be enhanced with additional hardware. An array processor, for example, could significantly shortened the computer-time used during this study. This would have had a positive impact on the cost comparisons.

Figure 6 (Map Pocket) has been provided for illustrative purposes. It represents a 1:50 000 supervised classification of land covers and uses with an area of approximately 360 square kilometers (139 square miles) in the study sub-region. Grassland is the dominant land cover class. The variability within this class was attributed to differing levels of biomass. Pearce (1980) investigated the utility of Landsat data for rangeland monitoring and concluded that biomass could be established in qualitative terms. This theory was subsequently applied to produce the high, moderate and low biomass rangeland classes. It was recognized that terrain features such as shadow, aspect and slope can produce spectral signatures similar to those which have been correlated solely with biomass. The influence of the terrain

Table 2

SUMMARY OF BENEFITS AND LIMITATIONS OF DIGITAL LANDSAT VERSUS CONVENTIONAL PHOTOGRAPHIC CLASSIFICATIONS OF LAND COVER AND USE

BENEFIT	LIMITATION
The digital format provides the user greater flexibility and digital images can be enlarged to any desired scale without the loss of inherent spectral resolution.	Digital enlargements for classifications larger than 1:50 000 result in a loss of ground resolution. Ground resolution is best at scales smaller than 1:50 000.
Digital images have consistent spectral tonal qualities and excellent spatial accuracy provided the image is corrected to the Universal Transvere Mercator system.	The cost, in terms of computer time, for a geometric correction is high, but comparable in cost to producing a controlled mosaic.
A digital image is superior to photographic images because it contains the maximum amount of information acquired by the satellite sensors. A photographic system is limited by the inability of normal film products to capture all the information delivered by its optics.	Processing costs of a digital image are relatively high as the hardware and software are expensive to purchase or use. Use of digital data also requires digital image analysis experience.
The high cost of computer time is offset by the lower cost of primary data (CCTs, etc.). Primary photographic data is very expensive.	
A supervised classification of digital data can produce results at a scale of 1:50 000 that are as rigorous as those obtained photographically for approximately the same cost.	The resource appraisal specialist must be proficient in the operation of the digital analysis system or must work closely with a technician.
	Classification overlap can occur using digital data. This factor can reduce the accuracy of the final classification. Overlap can be corrected but the cost associated with this is high in terms of additional primary data and computer time.
An unsupervised classification can be prepared by an image analysis system technician at a relatively low cost. This classification is most advantageous when the researcher has no independent information on the area to be classified, that is, the spectral reflectance of land covers is not known or there is no local knowledge of the area in question.	The unsupervised classification must be interfaced with information about the area to be interpreted. This information must be acquired through analysis of ground data.
Statistical algorithms can be used on an image analysis system to generate the relative percentage of a given class or classes for the study area or portions thereof. This can be performed very quickly and at very low cost. Obtaining this information from photographic classifications must be done manually with a planimeter or it can be digitized for computation. The cost of either approach is relatively high, however.	

factor, however, did not appear to play a very significant role. Biomass levels within the rangeland land cover class had a very prominent influence. Other features include barren lands (which consist of exposed mineral soils primarily in the Milk and Lost River canyons, and areas of high salt concentration), watercourses and waterbodies and wetland and riparian sites.

Figure 6 contains a very small percentage of unclassified pixels (0.2 per cent). Since it is not the intent of this project to produce a perfect classification of themes, hectare by hectare, post classification filtration has not been extensively used to clean-up 1:50 000 classifications. The improvements made to the classification are not very substantial and consequently do not justify the manpower and computer time expenditure.

Table 3 contains the percentage of geographic coverage of each class in Figure 6. This information can be generated quickly and at very little expense. This information can also be gleaned from a conventional air photo-derived land cover and use classifications, but costs incurred would be substantially greater because this task would be labour intensive.

6.3 Future Resource Management Applications

Digital Landsat data classifications of land cover and use at 1:50 000 could provide the ELS practitioner with a readily-available data source when very little or no information is available for the area in question at the initiation of a project. An unsupervised classification of land covers identifies homogeneous landscape features with a high degree of statistical confidence. While an interpretation of homogeneous land cover types is not provided by an unsupervised classification, the establishment of patterns in itself for use in an Ecological Land Classification (ELC) process may prove to be valuable, particularly when used with 1:250 000 or 1:50 000 Landsat hard copy images. The unsupervised classification performs a clustering task that an unaided visual interpretation cannot match for accuracy. Combined with existing resource inventories and ground data acquired during the ELC process, the unsupervised classification can become a useful tool.

This information has additional advantages. It can be produced to depict current and historical land covers at reasonable cost. In real cost terms an unsupervised classification for an average planning

Table 3

RELATIVE PERCENTAGE OF LAND COVER AND USE CLASSES DEPICTED IN FIGURE 6

CLASS	AREA IN		RELATIVE PERCENTAGE
	HECTARES	ACRES	
Water	175.3	433	0.5
Wetland	259	640	0.7
Riparian	589	1 454	1.6
Rangeland			
High Biomass	12 909.1	31 874	34.8
Moderate Biomass	13 551.3	33 460	36.6
Low Biomass	5 955.5	14 705	16.1
Agricultural Land (i.e. crop lands)	181	447	0.5
Barren Land	3 389.8	8 370	9.1
Unclassified	60	148	0.2
TOTAL AREA	37 070.3	91 532	100.1

area can be estimated at $2 400. Because computer time and technical assistance costs were absorbed by the Alberta Remote Sensing Center, actual costs to the department would include the costs of the Landsat CCTs and photographic scenes only. This factor would reduce the cost of the unsupervised classification by more than $1 000. This, of course, must assume that the planning area in question occurs within one Landsat scene. If overlap occurs, data acquisition costs must be increased proportionately with the number of CCTs that will be required.

Work conducted by Van Ravenswaay-Claasen (1981) suggested that the supervised classification has considerable value in the generation of an ELC. Further research should be conducted in this area to confirm this conclusion.

In addition, potential use of digitally-derived land cover classifications may be highest in the context of the integrated resource planning program when this information is produced to address a specific resource management problem or issue. The approach developed in this study for a supervised classification can, for example, be used to identify critical wildlife habitats that must be considered in the development of a resource allocation scheme (i.e. land use zoning). Bonner, Rohde and Miller (1981) demonstrated the utility of such classifications for planning purposes. Lower costs and greater assurances of utility are the most significant advantages to this specific use approach.

6.4 Future Investigations

This study was conducted in conjunction with the Alberta Remote Sensing Center. An ARIES II image analysis system was used by the research team to establish the technical and financial feasibility of Landsat digital data as a source of land cover and use information. The conclusions in this report are based solely on the team's experience with this system; consequently, high user training and familiarization time-related costs and system limitations are reflected in total costs itemized. These costs may therefore be higher than those incurred in an operational program. The private sector may also be capable of providing a similar product at lower cost.

Alberta Energy and Natural Resources is currently developing an operational base mapping program for the province centered on the Computer Graphics Mapping System (CGMS). The system has been designed for 1:20 000 scale base map production for the entire province and is sophisticated. It would be worthwhile to explore the possibility of using this system to produce Landsat data-derived land cover and use maps. The feasibility of system modification and its associated costs should subsequently be examined. High future educational costs to operate this system could be substantially reduced if CGMS staffing qualification criteria included proficiency in land cover and interactive image analyses.

Concurrent with an assessment of in-house potential, an assessment should also be conducted to determine whether the private sector can produce the desired products for integrated resource planning, and at what cost.

Finally, Landsat data application in the ELS process should be carefully examined. Current in-house reviews suggest that the great amount of field data required for a supervised classification of Landsat data is a major limitation. Once collected this information can be applied directly in a conventional ELC process. Secondly, because the conventional ELC approach uses existing air photo coverage which is relatively recent (i.e. seldom more than 10 years old) and extensive, the ELC can be produced at a comparatively low price. The greatest potential application for Landsat data exists where air photo coverage is not available, or where existing scales are too small in relation to the level of landscape generalization required in integrated resource planning. The Landsat 4 and 5 Thematic Mapper data may eventually rival conventional air photography. These preliminary conclusions require further study.

7. GLOSSARY OF TERMS

Ablation Moraine: Deposited from glacial material in transport upon or within the terminal area of a shrinking glacier. As the ice melts inward from the terminus, top and base the material slides, flows is dumped or subsides onto the ground. The resulting deposit or till is loose, non-compacted, non-layered and the particles show little signs of abrasion.

Algorithm: In computing, a software statement of the steps to be followed in the solution of a problem. In remote sensing, usually refers to a procedure, mathematical or otherwise, for manipulating digital data. In the context of the ARIES II image analysis system, examples include Interactive Training (IT) and Maximum Likelihood (ML).

Atmospheric Distortion: A reduction of reflectance measurements made from above or from within the atmosphere, caused by moisture and particles of matter in the atmosphere.

Band: A small continuum of wavelengths of the electromagnetic spectrum sensed by a multispectral scanner or passed by a band-pass filter and recorded on photographic film.

Biomass: The total quantity of living organisms of one or more species per unit of space, or of all the species in a biotic community.

CCT: Computer Compatible Tape. A data tape specifically formatted to be run on a computer system. The CCT is derived from a High Density Data Tape (HDDT) -- the format in which satellite and other data is originally captured and recorded. Standard scenes contained on LANDSAT MSS CCTs comprise 2 286 scan lines (or 381 swaths), each containing 3 240 pixels. Areal coverage is approximately 30 000 km^2.

Classification (Multispectral): An information extraction process that analyses the spectral signature, or vector, of each pixel and assigns that pixel to a category based on similar signatures. There are two general types of classification schemes: supervised and unsupervised.

Colour Infrared Photography: Is developed from film consisting of a green sensitive layer, a red sensitive layer and an infrared sensitive layer. On the finished film the green wavelengths are portrayed as blue, red is portrayed as green and the infrared is represented by red. Usually results in an overall red-pink appearance of the photo, and is used extensively for biophysical analysis of landscapes.

Contrast: Ratio of the energy reflected from two objects. Sufficient contrast permits distinguishing between those two objects on remotely-sensed data.

Data Set: A defined set of data (e.g. digital multispectral data for a defined area).

Decimation: Selecting for processing or display every fourth or tenth, etc. pixel and line of any image due to storage or video space limitations. This results in a reduction or decimation of the original data set.

DICS: Digital Image Correction System. Used by the Canadian Centre for Remote Sensing. It consists of a computer configuration which geometrically repositions the pixel of a standard CCT to conform to UTM coordinates. This format has a 50 square metre pixel with a linear accuracy of better than 0.5 pixel. Each DICS scene comprises spectral data in four bands of four adjacent 1:50 000 NTS Maps, or one quarter of a 1:250 000 NTS sheet (.5° latitude X 1° longitude).

Digital Image: Represents spectral or radiometric intensities of light reflected from the Earth's surface, acquired in discrete wavebands by the satellite, transmitted to an Earth Station and formated into a rastered, numerical array of those spectral values on computer tape.

Ecological Land Classification (ELC): Ranging from complex and broad area designations like tundra, prairie grassland and boreal forest through to less complex and smaller area designations like bottomland, tidal marsh and river terrace, these terms represent a series of generalizations. The generalizations derived primarily on the basis of the continuity of external land characteristics, are discerned by associated vegetation, topography, soils and climate. When they are grouped and ranked with greater scientific precision, the parts or categories of a hierarchy become apparent. Ecological Land Classification as practised in Canada consists of such a vertical and horizontal hierarchy, and provides a framework to comparatively index land ecosystems relative to each other (see Appendix 2). The subsequent analysis of these land ecosystems provides the basic resource information required for land resource planning and management.

Ecological Land Survey (ELS): An interdisciplinary approach derived by the Canada Committee on Ecological Land Classification (CCELC). It consists of three general parts: the Survey Proposal, the Ecological Land Classification and the Ecological Land Evaluation (see Appendix I). The ELS is pivotal upon viewing land as an ecosystem and, consequently, takes biotic and abiotic characteristics into account. As this approach establishes a broad data base, it allows for a variety of evaluations which will assist planning and management decision-making.

Geometric Correction: Spectral or spatial data which is referenced/registered to a co-ordinate system such as the Universal Transverse Mevcator (UTM) after undergoing spectral and geometric transformations.

Glacial Spillway: A channel which drained glacial melt-waters overflowing ice-dammed lakes during deglaciation of the Pleistocene continental (Laurentide) ice mass.

Ground Data: Supporting imperical data collected on the ground, and information derived thereof, as an aid to the interpretation of remotely-recorded surveys, such as airborne imagery, etc. Generally, this should be performed concurrently with the airborne surveys. Data on weather, soils and vegetation types and conditions are typical.

Ground Resolution: The size of the smallest detectable or measurable detail on remotely-sensed imagery.

Ground Track: The vertical projection of the actual flight path of an aerial or space vehicle onto the surface of the Earth or other body.

Ground Verification: Information derived from ground data and surveys to support interpretation of remotely-sensed data. Often referred to as ground truth.

Hardware: The physical components of a computer and its peripheral equipment. Contrasted with software.

Image: (1) The counterpart of an object produced by the reflection or refraction of light when focused by a lens or mirror. (2) The recorded representation (commonly as a photo-image) of an object produced by optical, electro-optical, optical mechanical, or electronic means. It is generally used when the EMR emitted or reflected from a scene is not directly recorded on film.

Image Analysis System: A collection of interconnected electronic components that allow the user to input data into the system; process the data using a series of software routines; and interact with the computer, software and image data to complete a given task.

Image Processing: Encompasses all the various operations that can be applied to photographic or image data in conjunction with a computer system. These include, but are not limited to, image decimation, image restoration, image enhancement, preprocessing, quantization, spatial filtering and other image pattern recognition techniques.

Infrared: Pertaining to energy in the 0.7-100 um wavelength region of the electromagnetic spectrum. For remote sensing, the infrared wavelengths are often subdivided into near infrared (0.7-1.3 um), middle infrared (1.3-3.0 um), and far infrared (7.0-15.0 um). Far infrared is sometimes referred to as thermal or emissive infrared.

Infrared Photographic: Pertaining to or designating the portion of the EM spectrum with wavelengths just beyond the red end of the visible spectrum; generally defined as from 0.7 to about 0.1 um, or the useful limits of film sensitivities.

Interactive: The continual back and forth process between a computer and operator where the computer gives prompts on completion of one session step and the operator chooses among the options given for continuing to the next.

Interactive Image Processing: The manipulation of original imagery data or processed imagery data by an operator or analyst for subjective evaluation.

Integrated Resource Planning: A co-operative and comprehensive approach to the establishment of plans and the delivery of benefits from the resource base in an efficient and effective manner.

Landsat: Originally known as the Earth Resources Technology Satellite (ERTS). A research and development tool to demonstrate that remote sensing from space was a feasible and practical approach to efficient management of Earth's resources. Landsat satellites 1, 2, and 3 contained two sensor systems: a return beam vidicon sub-system and a four-band multispectral scanner subsystem. Landsat-3 also had a five-beam multispectral scanner that includes one thermal infrared band.

Landsat-1: Originally ERTS-1, launched in June 1972 and ceased to function in January, 1978.

Landsat-2: Launched in January, 1975 and still functioning.

Landsat-3: Launched in January, 1978 and still functioning. The thermal band failed in July, 1978.

Landsat-4: Launched in July, 1982. It is equipped with a high ground resolution Thematic Mapper (TM) and standard Multispectral Scanner (MSS).

Landsat-5: Launched in March, 1984. Equipped similarly to Landsat-4.

Landsat Data: A four-band scene measuring 185 kilometres X 185 kilometres (115 statute miles X 115 statute miles). Pixels measure ground equivalent of 57 metres X 79 metres, or approximately 80 metres X 80 metres with sidelap. Worldwide coverage is between 80° north and 80° south.

Landsat MSS (Multispectral Scanner Sub-system): A four band optical-mechanical multispectral scanner. Works by scanning a swath of the terrain below the Landsat satellite. It sweeps the scene as the satellite moves over the Earth so that a continuous picture is captured line by line. The MSS records in four spectral bands namely the green, orange-red and two near infrared. Band 4 = 0.5-0.6 um (green), band 5 = 0.6-0.7 um (red), band 6 = 0.7-0.8 um (IR), and band 7 = 0.8-1.1 um (IR).

Landsat TM (Thematic Mapper): An advanced sensor system found on board Landsat 4 and 5 which incorporates the characteristics of the MSS with new improved spatial resolution (30 X 30 metre pixel size), expanded spectral coverage and high quantization accuracy.

Large Scale: (1) Aerial photography with a representative fraction of 1:500 to 1:50 000. (2) Maps with a representative fraction (scale) greater than 1:100 000.

Linear Feature: A two-dimensional, straight to somewhat curved line, linear pattern, or alignment of discontinuous patterns evident in an image, photo, or map, which represents the expression of some degree of linearity of a single or diverse grouping of natural or cultural ground features.

Laurentide Glacier: Represents the ice sheet that covered most of North America during the last glacial age.

Map: A representation in a plane surface, at an established scale, of the physical features (natural, artificial, or both) of a part of the Earth's surface, with the means of orientation indicated.

Map, Large-Scale: A map having a scale of which is greater than 1:100 000.

Map, Medium-Scale: A map having a scale from 1:100 000 to 1:1 000 000, inclusive.

Map, Small-Scale: A map having a scale smaller than 1:1 000 000.

Microfiche (Landsat): Microfilmed copy of a Band 6 image used to select Landsat scenes for ordering.

Mosaic, Controlled: An air photo mosaic prepared in association with ground control points. It uses prints that have been rectified as shown to be necessary by the control.

Multistage Inventory: One in which progressively more detail is obtained for progressively smaller sub-samples of the areas being studied.

Noise: Random or regular interfering effects in the data which degrade its information-bearing quality.

Orbit: (1) The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves. (2) To go around the Earth or other body in an orbit.

Overlap: The area common to two classes as apparent in a scattergram. A confusion zone.

Overlay: A transparent sheet giving information to supplement that shown on maps. When the overlay is laid over the map on which it is based, its details will supplement the map.

Photographic Interpretation: The process used to examine photographic images for the purpose of identifying objects and judging their significance. Photo interpretation, photointerpretation, and image interpretation are other widely-used terms.

Pixel: Derived from picture element. A data element having both spatial and spectral aspects. The spatial variable defines the apparent size of the resolution cell (i.e., the area on the ground represented by the data values), and the spectral variable (digital values) defines the intensity of the spectral response for that cell in a particular channel. Digital values range from zero (black) to 255 (white).

Platform: The vehicle or station from which remote sensing is carried out. These include towers, low altitude aircraft, high altitude aircraft and satellites.

Post-Classification Filtration: A computer task used to classify pixels which could not be classified during the training process.

Purity Filtration: A computer task used to remove potentially misclassified pixels during the training process.

Reconnaissance Level: The scale at which a cursory overview of a large geographic area can be obtained in a short time when little or no information is available. Scales used for reconnaissance level surveys or assessments are generally small but can range upward from 1:50 000.

Scale: The ratio of a distance on a photograph or map to its corresponding distance on the ground. Usually expressed as a representative fraction.

Scene: A geographic area portrayed on a Landsat image or image segment.

Seral: A biotic community which is developmental, transitory stage in an ecological succession.

Signature (Spectral): Any characteristic or series of characteristics by which an object or ground cover is recognized. Usually used in the sense of spectral signature, as in Landsat multispectral scanner data or photographic data.

The combination of digital values of reflected light that makes an object or ground cover unique.

Quantitative measurement of the properties of an object at one or several wavelength intervals.

Spectral Resolution: The finest separation that can be made between image details based on spectral data alone.

Software: The internal programs or routines professionally prepared and electronically stored in computer files to simplify programming and computer operations.

Spatial: Refers to the geograhic/locational/distributional components of Earth features or data.

Sun Synchronous: An Earth satellite orbit in which the orbital plane is near polar and the altitude such that the satellite passes over all places on Earth having the same latitude twice daily at the same local sun time.

Supervised Classification: A computer implemented process through which each measurement vector is assigned to a class according to a specified decision rule, where the possible classes have been defined on the basis of representative training samples of known identity.

Swath Width (Total Field of View): The overall plane angle or linear ground distance covered by a scanner in the across-track direction. Landsat MSS swath width is 185 km on the ground.

System: Structured organization of people, theory, methods and equipment to carry out an assigned set of tasks.

Temporal: The time component of Earth surface features or data (e.g. daily, seasonal, annual, frequent, occasional, cyclical, etc.).

Theme: A chosen or derived class or rendition of information representing homogeneous regions of unique spectral characteristics (signature). Synonymous with the word class.

Tone: Each distinguishable shade of grey from white to black on an image.

Training: Informing the computer system which sites to analyse for spectral properties or signatures of specific land cover classes; also called signature extraction.

Training Sites: Recognizable areas on an image with distinct (spectral) properties useful for identifying other similar areas.

Transformation: A spectrally- or spatially-altered array of data that has maintained its basic structure and meaning (e.g. scale changes, translation, rotation, rectification, etc.).

Unsupervised Classification: A computer-implemented process through which each measurement vector is assigned to a class according to a specified decision rule. This classification differs from the supervised classification in that only statistical properties of the image data is used as a basis for the classification. The operator determines the spectral ranges of bands to be analysed, and the number of distinct classes the computer is to generate.

UTM: Universal Transverse Mercator. A map projection system.

Vector: A quantity that has magnitude, direction and sense. A vector is commonly represented by a directed line segment, with length representing magnitude and orientation in space representing direction. The length and orientation of the line segment has a conveyed meaning or sense.

Wavelength: A unit of electromagnetic measurement that characterizes discrete types (colours) of energy.

8. REFERENCES

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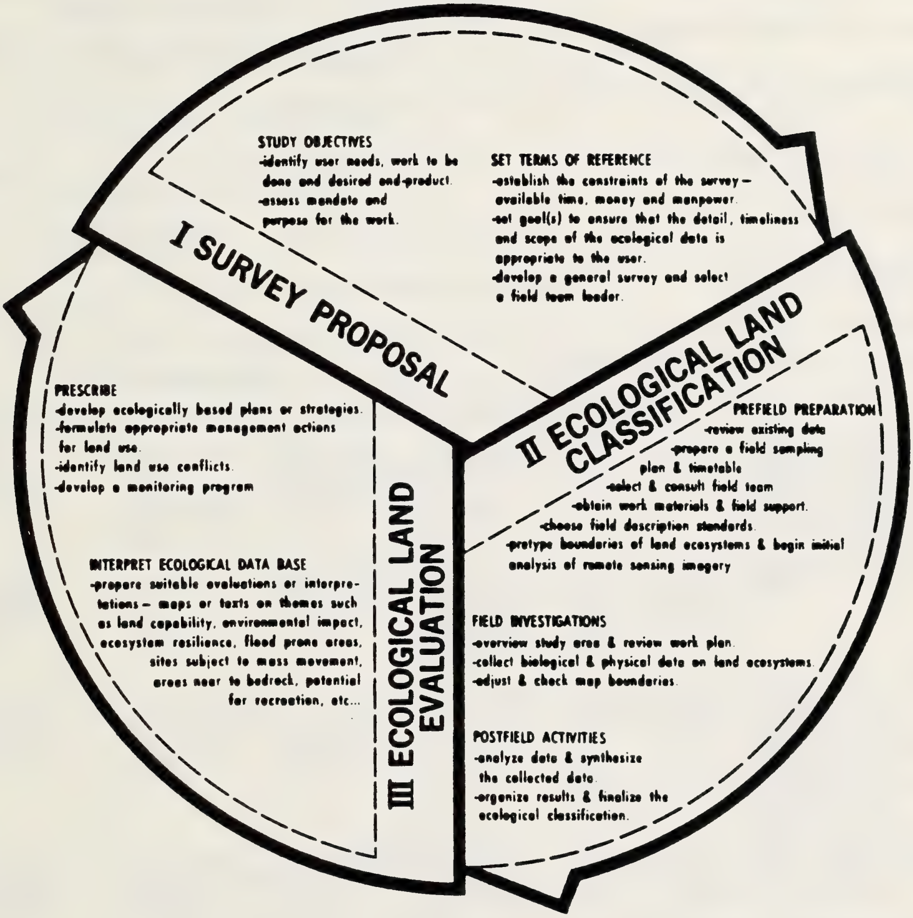
APPENDIX 1. COMPONENTS OF AN ECOLOGICAL LAND SURVEY


STUDY OBJECTIVES
-identify user needs, work to be done and desired end-product.
-assess mandate and purpose for the work.
SET TERMS OF REFERENCE
-establish the constraints of the survey – available time, money and manpower.
-set goal(s) to ensure that the detail, timeliness and scope of the ecological data is appropriate to the user.
-develop a general survey and select a field team leader.
I SURVEY PROPOSAL
II ECOLOGICAL LAND CLASSIFICATION
PREFIELD PREPARATION
-review existing data
-prepare a field sampling plan & timetable
-select & consult field team
-obtain work materials & field support.
-choose field description standards.
-pretype boundaries of land ecosystems & begin initial analysis of remote sensing imagery
FIELD INVESTIGATIONS
-overview study area & review work plan.
-collect biological & physical data on land ecosystems.
-adjust & check map boundaries.
POSTFIELD ACTIVITIES
-analyze data & synthesize the collected data.
-organize results & finalize the ecological classification.
III ECOLOGICAL LAND EVALUATION
PRESCRIBE
-develop ecologically based plans or strategies.
-formulate appropriate management actions for land use.
-identify land use conflicts.
-develop a monitoring program
INTERPRET ECOLOGICAL DATA BASE
-prepare suitable evaluations or interpretations – maps or texts on themes such as land capability, environmental impact, ecosystem resilience, flood prone areas, sites subject to mass movement, areas near to bedrock, potential for recreation, etc...

ECOLOGICAL LAND SURVEY

Source: Wiken and Welch (1979).

APPENDIX 2

LEVELS OF ECOLOGICAL GENERALIZATION PROPOSED BY THE CANADA COMMITTEE ON ECOLOGICAL (BIO-PHYSICAL) LAND CLASSIFICATION

Definitions for the levels of generalization

Ecoprovince - an area of the Earth's surface characterized by major structural or surface forms, faunal realms, vegetation, hydrological soil and climatic zones.

Ecoregion - a part of an ecoprovince characterized by distinctive ecological responses to climate as expressed by vegetation, soils, water, fauna, etc.

Ecodistrict - a part of an ecoregion characterized by a distinctive pattern of relief, geology, geomorphology, vegetation, soils, water, and fauna.

Ecosection - a part of an ecodistrict throughout which there is a recurring pattern of terrain, soils, vegetation, waterbodies, and fauna.

Ecosite - a part of an ecosection having a relatively uniform parent material, soil and hydrology, and a chronosequence of vegetation.

Ecoelement - a part of an ecosite displaying uniform soil, topographical, vegetative and hydrological characteristics.

LEVEL OF GENERALIZATION			COMMON FACTORS OF RECOGNITION			
Common map scale*	Geomorphology	Soils	Vegetation#	Climate	Water°	Fauna
ECOREGION 1:3 000 000 to 1:1 000 000	Regional landforms or assemblages of regional landforms	Great groups or assemblages of grt. groups	Plant regions or assemblages of plan regions	Meso or small scale	Water regime	High species diversity; may correspond either to a widely distributed species (e.g. deer, mouse), or to the habitat of individuals within a species.
ECODISTRICT 1:500 000 to 1:125 000	Regional landform or assemblages thereof	Assemblages of soil associations	Plant districts or assemblages of plant districts	Meso or large scale micro	Drainage pattern; water quality	
ECOSECTION 1:250 000 to 1:50 000	Assemblages of local landforms or a local landform	Soil associations and assemblages thereof	Plant Associations or a plant association	Large scale micro to small scale micro	River reaches, lakes and shoreland	Less diverse species complement habitat requirements of typical species more restricted (e.g. beaver, otters); may coincide with specialized areas of animal total habitat (e.g. wintering area, calving grounds).
ECOSITE** 1:50 000 to 1:10 000	A local landform or portion thereof	Soil series or a series complex	Plant association or serial stage	Large scale micro	Subdivision of above	
ECOELEMENT 1:10 000 to 1:2 500	Portion of or a local landform	Phases of soil series or a soil series	Parts of a plant association or subassociation	Small scale micro	Sections of small streams	Low species diversity habitat of small manals, reptiles and amphibians etc., specialized areas of some fauna's habitat requirements (e.g. denning areas, local wintering deer yards).

* Map scales should not be taken too restrictively, as they will vary with the environment setting and objectives of the survey.

** This level is frequently subdivided into phases according to the stage of plant succession.

# These vegetative groupings are only suggested ones; agreement on a common system is yet to be achieved.

° See D. Welch, 1978. LAND/WATER CLASSIFICATION. ELC Series No. 5, Lands Directorate, Ottawa.

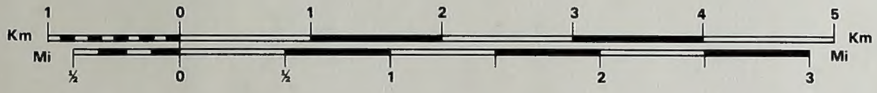
Source: CCELC Newsletter No. 6, 1979. E. Wiken, Editor. Lands Directorate, Environment Canada. Ottawa.

Figure. 6

LAND COVER AND USE CLASSIFICATION FROM DIGITAL (MSS) LANDSAT DATA* IN THE

MILK RIVER REGION

SCALE 1 : 50 000



West of the Fourth Meridian

LEGEND

🟥 **WATER**

Applies mainly to permanent watercourses (Milk River) and low lying sites where water may accumulate.

Some classification overlap or confusion between high biomass **rangeland** and **water** is apparent. Shadows cast on the north-west facing slopes of coolees are also confused with water. These misclassifications of are the result of a very high degree of similarity in spectral signatures amoung these features.

🟪 **WETLAND**

An area of emergent aquatic vegetation where the water table stands at or above the land surface for at least part of the year.

Permanent waters of streams, reservoirs and deep lakes are not included. Areas of ephemeral water are also not included since they have little or no effect on the development of hydric vegetation.

🟧 **RIPARIAN**

Land bordering streams or rivers. These areas have diverse vegetation: cottonwoods and willows are conspicuous features along the Milk River; willows are dominant along small streams.

RANGELAND

Land where the natural community of plants is dominated by grasses, forbs or shrubs. Grazing by livestock and big game animals has an important influence on these natural plant communities. Management by ecological rather than agronomic principles is more applicable in these areas.

This classification has three categories based on biomass levels that reflect the local ecological conditions and/or grazing intensity.

🟩 **High Biomass**

🟩 **Moderate Biomass**

🟨 **Low Biomass**

⬜ **AGRICULTURAL LAND**

Lands used primarily for the production of forage and cereal crops.

🟫 **BARREN LAND**

Exposed mineral soil which will not sustain vegetation due to aspect, slope disturbance or high salinity.

Areas prone to high accumulation of salts due to evaporation (salt evaporites) are depicted within this class.

This class also includes lands which are bare due to agricultural practices such as cultivation or summer fallow. The location of this sub-class is associated with agricultural land.

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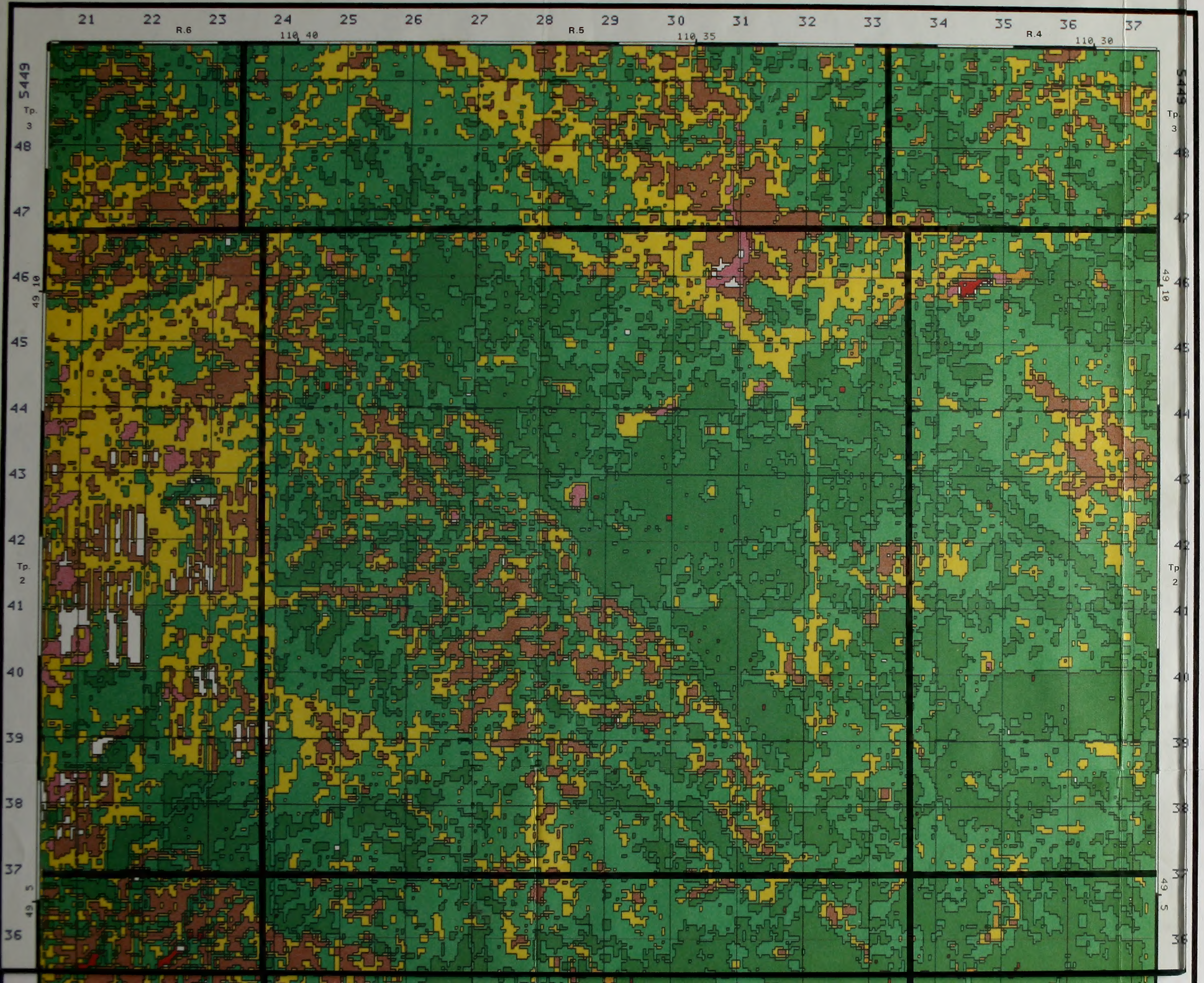
* This supervised classification is based on MSS data from **Landsat 2** on bands **4**, **5**, **6**, and **7**. The scene date is August 25, 1981. The classification was performed by an image analysis system (**ARIES II**) at the Alberta Remote Sensing Center.



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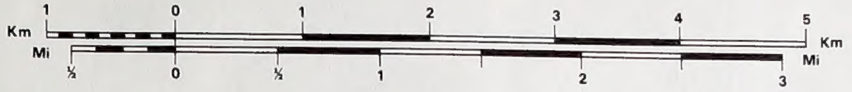

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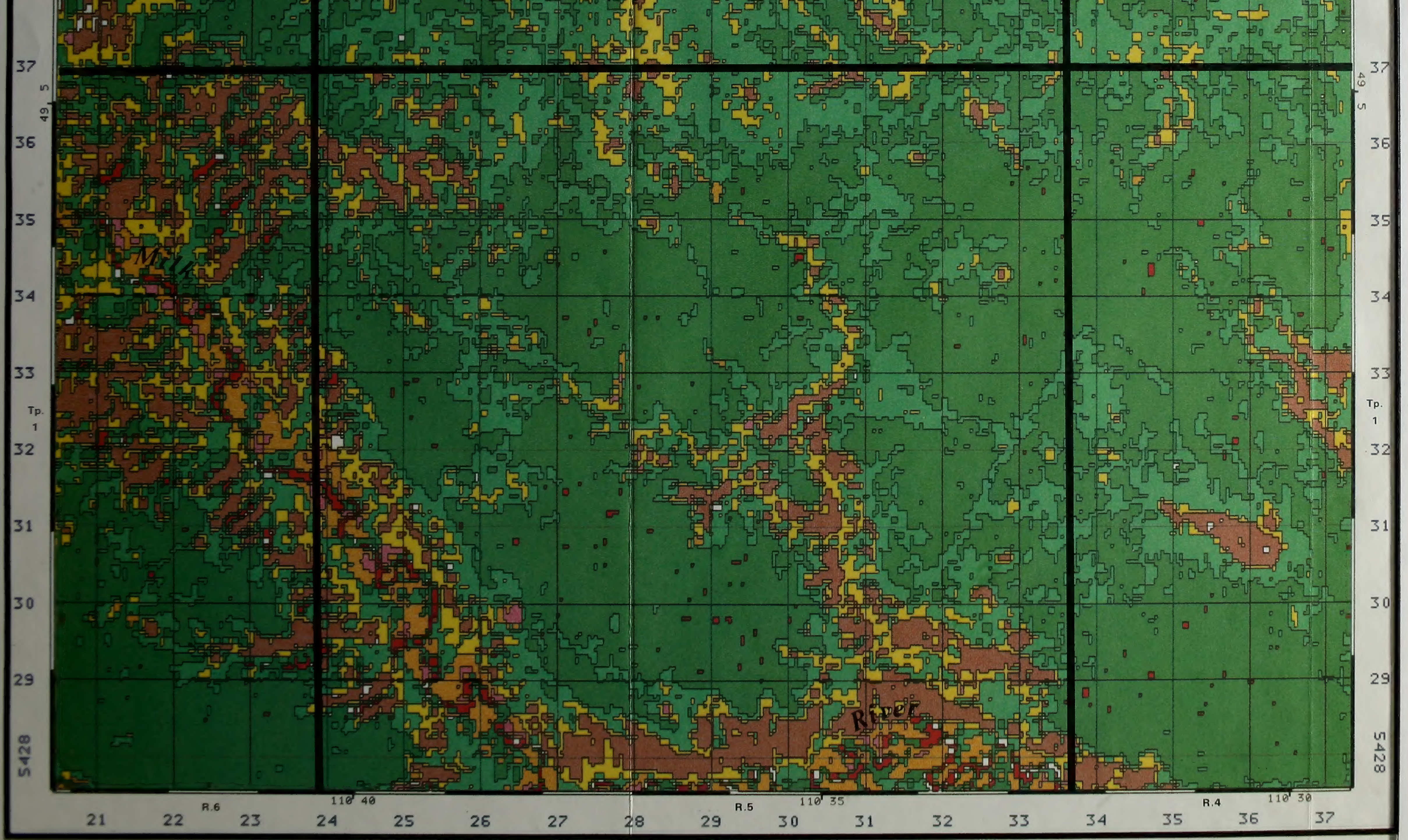

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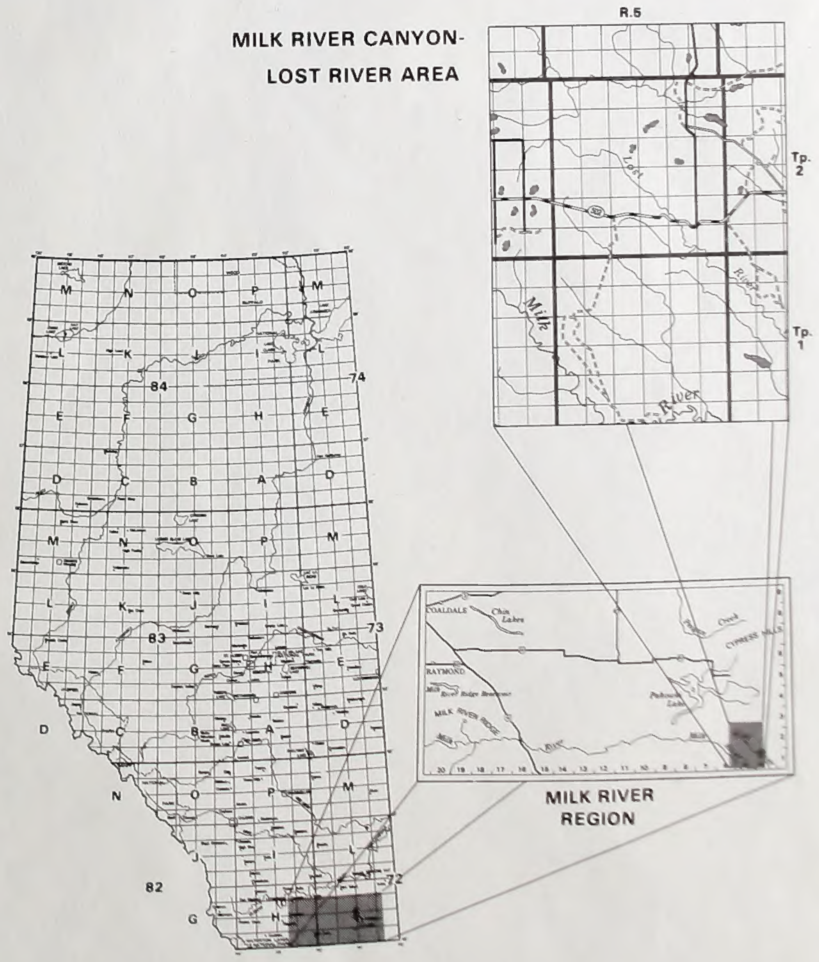
LOCATION OF AREA DEPICTED



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